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A Research and Development Laboratory (R&D Lab) concept for the Development of Technical Superconductors

L. Bottura (CERN), A. Ballarino (CERN), F. Bordry (CERN), A. Devred (CERN)
B. Holzapfel (KIT)
C. Senatore (University of Geneva)
D. Larbalestier (NHMFL), L. Cooley (NHMFL)

1. Introduction

Superconductivity is a core technology that has fueled the progress in high-energy physics (HEP) accelerators, from the Tevatron of the early 1980's to the Large Hadron Collider of the late 2010's [78Wil, 91Mei, 03Ane, 04Eva]. The engineering knowledge of superconducting materials in the form of composite wires, tapes, or thin layers finds application in high-field accelerator magnets [12Bot], very large detectors magnets [12Yam] and high-gradient/low-loss RF cavities [08Fur]. The progress witnessed in the past years has been remarkable. Comparable progress will be required to meet a number of HEP challenges in the close future, and mainly:

- Realize ultimate performance in Nb_3Sn, as it has been specified [15Bal, 19Bal] for the realization of the main magnets of a next step hadron collider such as the FCC Future Circular Collider (FCC) [18Ben] or other projects of similar scope;
- Demonstrate the potential of HTS materials to surpass LTS accelerator magnet technology, providing efficient very-high-field or high operating margin options for specific locations in existing and future colliders, and eventually to extend the energy reach of circular synchrotrons [14Bar].

This success was possible so far thanks to a *virtuous circle* of applied superconductivity, encompassing fundamental science, applied research and industrial production. Due to several factors, we observe that this virtuous circle is losing its effectiveness[1]. This is perceived as a serious threat to the future of a robust applied superconductivity program for HEP, and is the main reason why we propose to secure the technology by founding a Research and Development Laboratory for Applied Superconductivity that will work as a bridge between academia and industry. This proposal is driven by the need identified above, and commented below. The implementation should be of collaborative nature, i.e. localized in a number of associated institutes. Finally, this paper is a follow-up of the proposal originally submitted for

[1] Though the trend is indeed general, this statement applies to a different degree depending on the world region. The US-DOE SBIR and STTR funding mechanisms still provide means to perform applied research, with strong focus on HTS. The Japanese financing of R&D in industry also provides some resilience to the shift in industrial and academic priorities. Finally, China still profits from large investment capability for priority programs.

discussion at the Open Symposium on the Update of the European Strategy for Particle Physics (Granada, May 2019) [18Bot].

2. The *virtuous circle* of applied superconductivity

Under the *virtuous circle* of applied superconductivity, we intend the combination of the following elements:

- The challenging performance demands driven by specific project and studies for HEP, providing a forceful *pull*;
- The response provided by the R&D potential of universities and research institutes, the academic *scout*, where a superconductor discovery is made into a candidate technical material;
- The path from the discovery of a superconductor to a successful application requires that research work is extended from fundamental aspects to applied science and material engineering. This step demonstrates feasibility and performance, including considerations of scalability of the conductor architecture. So far this was the fruit of joint work of academia and industry. This part of the process provided a *bridge* between towards large scale industrial production;
- Industry is most effective when devising production routes, exploiting opportunities beyond a specific project, and profit from the associated *market*. This is an important step that provides long term support to the technology, and cost-effective standard superconductors: the *run*.

Though a rather simple representation of the process, the above description is sufficiently close to reality and provides a speaking image, see Fig. 1. The key element in the circle is that the *bridge* has been effectively shared between academia and industry, whereby the boundary between technology demonstration and industrial production remained rather fluid.

The past years have witnessed a considerable shift in the structure, mode of operation and priorities of research institutions, funding agencies and industry. In the new landscape, the above model of a virtuous loop appears to be much less likely to operate. Applied superconductivity no longer appears in high-priority research objectives of leading academia. At the same time, superconductors are considered as a commodity in a highly competitive market. The reduced profit margins leave little space to develop new technologies in industry. In summary, while the *pull* remains strong, and the *scouting* for new materials continues at a fundamental level, the link to a successful and profitable industrialization *run* has weakened. We start lacking a solid *bridge* to connect basic materials to industrial grade technical superconductors.

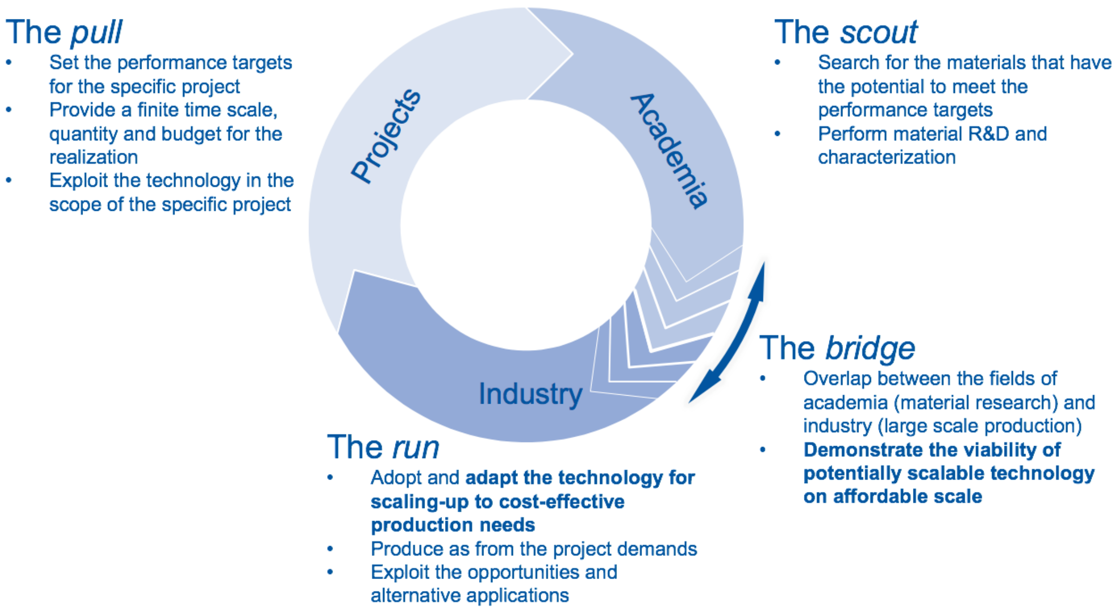

Figure 1. A schematic view of the *virtuous circle* of development of technical materials for superconducting applications, as it has been established and has been effectively working in the past. Note the overlap between academia and industry in the *bridge* area.

We can identify two main risks to the long-term future of superconductors for HEP, namely:

- The lack of an effective *bridge* between academia and industry may throttle the continuous advances in the performances of LTS and HTS demanded by HEP, or such a response may be possible only through an exceedingly large funding effort to cover the full cost of the R&D in academia and industry;
- In a market that is not self-sustained, and with a high volatility, know-how critical to the realization of high-performance superconductors specific to HEP may be lost.

3. A proposal

In the situation described in the Sect. 3, it is mandatory to develop a new mechanism to secure the long-term future of the technology of superconducting materials, wires, tapes and cables for accelerator magnets. The sought mechanism should span the field and include both LTS and HTS materials so to anticipate on future demands. The proposed solution is to create an *institutional bridge*, founding a laboratory for research and development in applied superconductivity that would host critical technology on long term, and act as a perennial connection of academia and industry. We refer to this new actor as a Laboratory for R&D on Applied Superconductivity (SC R&D Lab), shown schematically in Fig. 2.

In the above intentions, the main SC R&D Lab mission should be to drive and accompany the transition from basic material science performed in academia, to technical superconductors and cables relevant for industrialization. The facilities of the SC R&D Lab would be used to try out novel ideas in term of materials, compositions and architectures, test manufacturing processes on a reduced scale and affordable cost, without the overheads of the infrastructure necessary for production on large scale. The scope of work should cover both LTS and HTS in their different forms (wire and tapes). The SC R&D Lab would only need pilot production capability for demonstration purposes. In the case of LTS a suitable length scale for demonstration is few hundreds of meters, which could be used in demonstration cables. For HTS, of higher inherent complexity, a suitable scale would be few tens of meters. This R&D would proceed in a manner enabling assessment of not just R&D potential, but also of the capability for industrial manufacture, where costs are much larger.

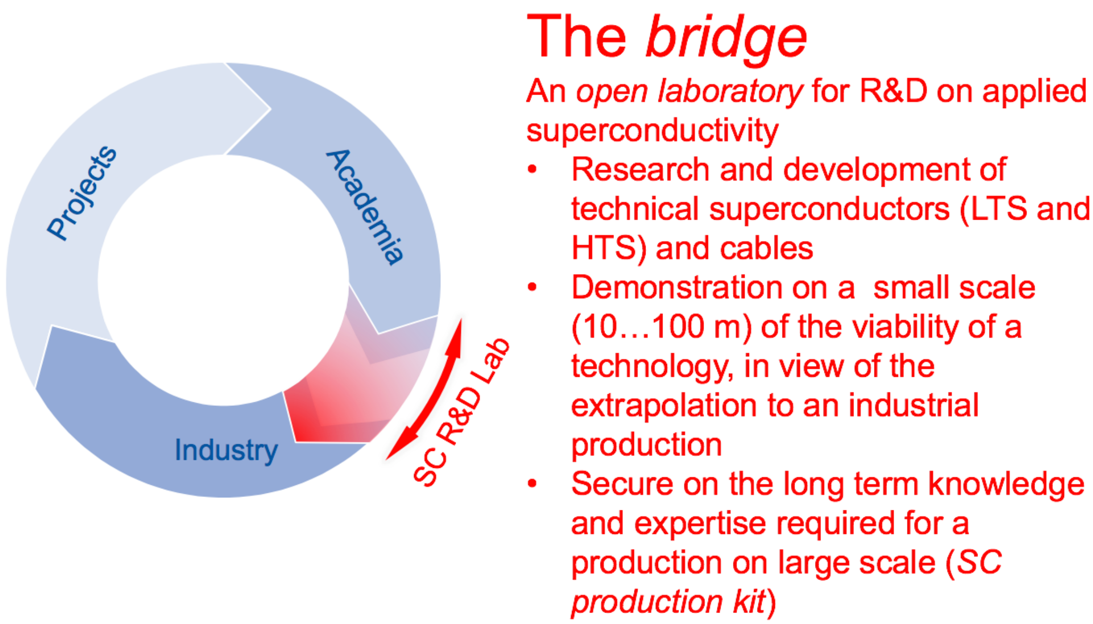

Figure 2. The present state of the *virtuous circle* of applied superconductivity, with retracting academic and industrial participation, and the proposed solution of an R&D Laboratory in Applied Superconductivity that should take the function of the *bridge*.

Besides the main aim of acting as the *bridge* between material R&D and industrial scale production, a SC R&D Lab would unite and secure on the long-term the competences and the critical intellectual property in applied superconductivity, as required by HEP, from material inception to production. At the same time, one such laboratory would be the ideal hub to train the new generation of applied physicists and engineers in applied superconducting material science and technology.

The SC R&D Lab infrastructure and operation would require the support of services (e.g. chemistry, clean assembly and welding, machining, heat treatments), as well as characterization and measurement facilities of various type and technology. It is not in the intention of this proposal to recreate a pole with the required capabilities, but rather to use existing facilities and capabilities located in many of the laboratories and universities associated to HEP.

4. Present capability and proposed network

The idea of an institutional SC R&D Lab in the form presented above is new. Nonetheless, as it should be clear from the previous narrative, it draws largely on previous experience. In spite of the fact that academic interest in this work has strongly reduced in the past years, a few institutes worldwide have some capability for the realization of demonstration LTS and HTS conductors. Below we report a non-exclusive list of those that are most active in the field.

In the case of LTS there is an heritage, whereby present work has been spurred by the request of high-performance Nb_3Sn for a future hadron collider [14Bal]. Mono- and multi-filamentary wire samples can be prototyped by a co-proposer at University of Geneva (Geneva, CH), and by co-proposers at the Applied Superconductivity Center of the NHMFL at FSU (Tallahassee, FL, USA). Other operations rely on small scale industrial production (e.g. University of Cambridge associated with Epoch Wires Ltd., or Ohio State University associated with Hypertech Inc). Existing facilities for LTS would need to be recovered, rejuvenated and complemented by state-of-the-art processing and control infrastructure, and a solid technology support, which is part of this proposal.

In the case of HTS, with significant potential for discovery and advance, the academic case is still of interest. A truly worldwide development community exists. However, the development groups tend to be focused on specific materials and routes, and the infrastructure is appropriate for small-scale operation short of the objectives of the proposed SC R&D Lab. The groups that have capabilities aligned with the proposed objectives are those available to one of the co-proposers at KIT-ITEP (Karlsruhe, DE), and the Texas Center for Superconductivity at the University of Houston (Houston, TX, US).

In the varied landscape described above, the SC R&D Lab itself does not need to be sited in a unique geographical location. Indeed, we could envisage a limited number of well-equipped and supported hubs (e.g. one for LTS and one for HTS located in Europe) which could function as the centers of a tight and well-coordinated collaboration among universities, institutes and, possibly, industry.

5. Opportunities and open access

The need identified in this proposal is not exclusive to HEP. We postulate, rather logically, that other Big Science projects such as thermonuclear fusion (DEMO), or magnet technology for medical applications such as ultra-high-field MRI will benefit from the existence and results of a SC R&D Lab. In fact, one such institutionally funded center may in last analysis also benefit industry. Indeed, in several cases industry has difficulties in justifying development when existing technology is sufficient to satisfy present needs (e.g. power applications). An *open* SC R&D Lab could provide sufficient advancement and momentum to justify a business case, so that industry would eventually transit to parallel high-technology avenues even in presence of an established product. This possible collateral effect may lead to societal impact beyond the science that a SC R&D Lab would serve, including training of the new generation of scientists and technicians, and should not be neglected.

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